The Impact of FEC on Mobile Multicast Power Control

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***Abstract*—3GPP has standardized the use of forward error correction for the provision of reliable data transmission in the mobile multicast framework. In this paper we present a study of the impact of application layer forward error correction on power control during mobile multicast transmission. The evaluation is performed with the aid of a novel scheme that allows the simulation of FEC impact on both streaming delivery and download delivery over a multicast session. It is important that the proposed scheme incorporates the properties of an evolved mobile network, as they are determined by the 3GPP specifications.**

Keywords- mobile networks; multicast; forward error correction; power control

I. Introduction

Forward Error Correction (FEC) is an error control method that can be used to augment or replace other methods for reliable data transmission. The main attribute of FEC schemes is that the sender adds redundant information in the messages transmitted to the receiver. This information allows the receiver to reconstruct the source data. Such schemes inevitably add a constant overhead in the transmitted data and are computationally expensive. In multicast protocols, however, the use of FEC has very strong motivations in comparison with other techniques that provide reliability in multicast transmission e.g. the Automatic Repeat re-Quest (ARQ) [9]. The FEC encoding eliminates the effect of independent losses at different receivers. This makes these schemes able to scale irrespectively of the actual loss pattern at each receiver. Additionally, the dramatic reduction in the packet loss rate largely reduces the need to send feedback to the sender; a process that is rather expensive in mobile networks in terms of power consumption and due to limitations of the communication infrastructure. FEC schemes are therefore so simple as to meet a prime objective for mobile multicast services; that is scalability to applications with thousands of receivers. This is the reason why 3GPP recommends the use of FEC for Multimedia Multicast/Broadcast Service (MBMS) and, more specifically, adopts the use of Raptor FEC code [2].

The standardization of MBMS by 3GPP triggered the research over FEC in the domain of mobile networks multicasting. Even though this research area is relatively new, a lot of solutions have been proposed so far. A very representative work is presented in [5] where a probabilistic model is used for the multicast user distribution in the network a scheme that combines FEC with traditional ARQ is defined for multicast data delivery. In this framework the impact of FEC use is investigated. Despite the high quality and the scientific vigor of the published studies, none of them presents a complete evaluation study on the use of FEC in power control of mobile multicast. Moreover, the majority of the published studies are based on the traditional UMTS system and the application of FEC has not presented in a framework that incorporates the evolution of UMTS beyond its 3rd generation.

In this paper, we study the applicability of FEC via Raptor code on the multicast data transmission in mobile networks. Our work focuses on the power control in the Radio Access Network (RAN). The evaluation is performed with the aid of a novel scheme that incorporates the properties of an evolved mobile network that uses High-Speed Downlink Packet Access (HSDPA) technology for high speed data delivery to mobile terminals. We examine through simulation experiments whether FEC is beneficial, how the FEC code overhead varies based on the network conditions and how this overhead affects the consumption of network resources. Our assessment is not only from power consumption point of view but also from energy consumption and time perspective. It is important that our analysis is compliant with the 3GPP specifications and considers the point-to-point (p-t-p), the point-to-multipoint (p-t-m) as well as the hybrid transmission that combines both bearers in the RAN. It is our belief and a motivation behind our study that the multicast user distribution is an aspect of major importance in multicast data delivery over mobile networks which has not been considered so far.

II. Multimedia Broadcast/Multicast Service

In this section, we briefly provide some fundamentals of mobile networks multicasting.

A. Overview

MBMS is a p-t-m service in which data is transmitted from a single source entity to multiple recipients. It provides the end user with two MBMS User Services; streaming delivery for real-time multimedia streams and download delivery for reliable multicasting of files. 3GPP has specified that these MBMS delivery methods make use of MBMS bearers for content delivery but may also use the associated delivery procedures for quality reporting and file repair. Streaming data such as video streams, audio programs or timed text being encapsulated in RTP are transported over the streaming delivery network. On the other hand, during download delivery, discrete objects such as still images, text, multimedia data encapsulated in 3GPP file formats or other binary data are transported using the File Delivery over Unidirectional Transport (FLUTE) protocol when delivering content over MBMS bearers [2].

Power control is one of the most critical aspects in MBMS. The downlink transmission power in mobile networks is the scarcest resource and, thus, it should be optimally utilized. The main purpose of power control is to minimize the transmitted power, thus avoiding unnecessary high power levels and eliminating inter-cell interference. 3GPP specifies that MBMS data delivery in the RAN can be provided by either multiple p-t-p channels or by a single p-t-m channel. The most important types of downlink transport channels are the High Speed-Downlink Shared Channel (HS-DSCH) and the Forward Access Channel (FACH). The HS-DSCH has been introduced for HSDPA operation and is a p-t-p transport channel shared by several UEs. The FACH is a p-t-m channel and, consequently, a single FACH can carry information for more than one UE in a cell [4].

During the p-t-p downlink transmissions through HS-DSCH, fast power control is used to maintain the quality of the link and thus to provide a reliable connection for the receiver to obtain the data with an acceptable error rate. Transmitting with just enough power to maintain the required quality for the link also ensures that there is minimum interference affecting the neighboring cells. However, when a user consumes a high portion of power, more than actually is required, the remaining power, allocated for the rest of the users, is dramatically decreased, thus leading to a significant capacity loss in the system [7], [8].

During p-t-m (i.e. broadcast) downlink transmissions through FACH, base station transmits at a power level that is high enough to support the connection to the receiver with the highest power requirement among all receivers in the multicast group. This would still be efficient because the receiver with the highest power requirement would still need the same amount of power in a unicast link, and by satisfying that particular receiver's requirement, the transmission power will be enough for all the other receivers in the multicast group. Consequently, the transmitted power is kept at a relatively high level in most of the time, which in turn, increases the signal quality at each receiver in the multicast group. On the other hand, a significant amount of power is wasted and moreover inter-cell interference is increased [7], [8].

As a consequence, downlink transmission power has a key role in MBMS planning and optimization. The following paragraphs provide an analytical description of the HS-DSCH and FACH power profiles and their power consumption characteristics during MBMS transmissions.

B. HS-DSCH Power Profile

HS-DSCH is a rate controlled rather than a power controlled transport channel. In HSDPA, the fast power control characterizing Release '99 channels is replaced by the Link Adaptation functionality, including techniques such as dynamic Adaptive Modulation and Coding (AMC), multi-code operation, fast scheduling, Hybrid ARQ (HARQ) and short Transmission Time Interval (TTI) of 2ms [3], [8].

The HS-DSCH Signal-to-Interference-plus-Noise Ratio (*SINR*) actually constitutes a new evaluation metric that slightly differentiates HSDPA from that traditionally used in Release '99 bearers. Release '99 typically uses E_b/N_0 (received-energy-per-bit-to-noise ratio) that corresponds uniquely to a certain Block Error Rate (BLER) for a given data rate. E_b/N_0 metric is not an attractive measure for HSDPA because the bit rate on the HS-DSCH is varied every TTI using different modulation schemes, effective code rates and a number of High Speed-Physical Downlink Shared Channel (HS-PDSCH) codes. *SINR* for a single-antenna Rake receiver is calculated as in Equation (1), [8]:

$$SINR = SF_{16} \frac{P_{HS-DSCH}}{(1-\alpha)\cdot P_{own} + P_{other} + P_{noise}} \quad (1)$$

$P_{HS\text{-}DSCH}$ is the HS-DSCH transmission power, P_{own} is the own cell interference experienced by the mobile user, P_{other} the interference from neighboring cells and P_{noise} the Additive White Gaussian Noise. Parameter α is the downlink orthogonality factor ($\alpha = 1$ denotes perfect orthogonality), while SF_{16} is the spreading factor of 16.

Moreover, there is a strong relationship between the HS-DSCH allocated power and the obtained MBMS cell throughput. This relationship can be disclosed in the three following steps. Initially, we have to define the target MBMS cell throughput. For instance, if a 64 Kbps MBMS service should be delivered to a multicast group of 10 users, then the target throughput will be equal to 640 Kbps. Once the target cell throughput is set, the next step is to define the way that this throughput relates to the SINR.

Finally, we can describe how the required HS-DSCH transmission power ($P_{HS\text{-}DSCH}$) can be expressed as a function of the SINR value and the user location, in terms of Geometry factor (G), as in Equation (2), [8]:

$$P_{HS-DSCH} \geq SINR[1 - a + G^{-1}]\frac{P_{own}}{SF_{16}} \quad (2)$$

The G is given by the relationship between P_{own}, P_{other} and P_{noise} and is defined from Equation (3), [8]:

$$G = \frac{P_{own}}{P_{other} + P_{noise}} \quad (3)$$

The G is another major measure that indicates the users' position in a cell (distance from the base station). A lower G is expected when a user is located at the cell edge (where interference received from the neighboring cell is higher than the interference experienced in its own cell). Moreover, in micro-cells MBMS users experience a better (higher) G due to the better environment isolation that leads, in turn, to lower inter-cell interference (P_{other}).

C. FACH Power Profile

FACH is a p-t-m channel that is received by all users throughout the service area of the cell (i.e. broadcast transmission). A FACH essentially transmits at a fixed power level since fast power control is not supported. FACH transport channel is multiplexed to a Secondary-Common Control Physical Channel (S-CCPCH) and specific levels of data rates are achieved depending on the used S-CCPCH slot format. The FACH fixed power should be high enough to ensure the requested QoS in the desired area of the cell and serve the user with the worst path loss, i.e. the user with the higher distance from the base station. TABLE I presents some indicative FACH downlink transmission power levels obtained for various cell coverage areas and for different BLER targets. These FACH transmission power levels correspond to a macro-cell environment (site to site distance 1 Km), when a 64 Kbps MBMS service is delivered. TTI is set to 80ms and no Space Time Transmit Diversity (STTD) is assumed [1], [8].

TABLE I. REQUIRED FACH TX POWER LEVELS VS. CELL COVERAGE IN MACRO-CELL ENVIRONMENT FOR DIFFERENT BLER TARGETS (64 KBPS).

Cell Coverage (%)	Tx Power for 1% BLER (W)	Tx Power for 5% BLER (W)	Tx Power for 10% BLER (W)	Tx Power for 20% BLER (W)
70	3.6	2.8	2.3	1.8
90	6.4	5	3.9	3.2
100	10.2	7.8	5.4	4.1

D. Raptor Codes for FEC

3GPP standardized Raptor codes as the application layer FEC codes for MBMS aiming to improve service reliability. Both the streaming delivery and download delivery methods in MBMS mandate that the UE supports Raptor codes. During streaming delivery, application layer Raptor codes are applied on UDP flows, either individually or on bundles of streams. On the other hand during download delivery method FLUTE protocol provides reliability using Raptor FEC [2].

Raptor codes are fountain codes, meaning that as many encoding symbols as desired can be generated by the encoder on-the-fly from the source symbols of a source block of data. The decoder is able to recover the source block from any set of encoding symbols only slightly more in number than the number of source symbols. The Raptor code specified for MBMS is a systematic fountain code producing n encoding symbols E from $k < n$ source symbols C. For more information on Raptor codes the reader is referred to [2].

Raptor codes have a performance very close to ideal, i.e., the failure probability of the code is such that in case is only slightly more than k symbols are received, the code can recover the source block. In fact, for $k > 200$ the small inefficiency of the Raptor code can quite well be modeled by the Equation (4). The failure probability of the code with k source symbols if m symbols have been received is denoted by $p_f(m,k)$. It has been observed that for different k, the equation almost perfectly emulates the code performance. While an ideal fountain code would decode with zero failure probability when $m = k$, the failure for Raptor code is still about 85%. However, the failure probability decreases exponentially with increasing number of received symbols [9].

$$p_f(m,k) = \begin{cases} 1 & if\ m < k, \\ 0.85 \times 0.567^{m-k} & if\ m \geq k. \end{cases} \quad (4)$$

III. SIMULATION EXPERIMENTS

The present section describes our simulation environment, the introduced scheme and the results of our simulation experiments.

A. Simulation Environment

The main difficulty in the assessment of MBMS service performance is the existence of a large number of system parameters in the system and the complexity of the involved components. Our intention is to make a parameter selection as generic as possible so as to have a simulation environment that is reasonably representative of the system behavior. Therefore, for the purpose of the simulation experiments a typical macro-cell environment is considered. The typical environment parameters that are chosen for the simulation based on [6], are presented in TABLE II. It should be noted that no STTD is employed in our simulation.

TABLE II. SIMULATION ENVIRONMENT PARAMETERS.

Parameter	Value
Cellular layout	Hexagonal grid
Number of cells	18
Site-to-site distance	1 km
Maximum BS Tx power	20 W
Other BS Tx power	5 W
Common pilot channel power	2 W
Common channel power	1 W
Propagation model	Okumura Hata
Multipath channel	Vehicular A (3 km/h)
Orthogonality factor	0.5

The simulation takes into account the properties of the RAN transport channels and their power consumption characteristics during MBMS transmissions. Therefore it is possible to examine the various effects of data delivery over mobile networks in a realistic way under various network configurations and channel conditions. Additionally, our scheme incorporates all the properties of a typical Raptor code defined for data delivery over MBMS as they are described by 3GPP in [4].

Our intention is to conduct simulation experiments that cover both MBMS User Services. Therefore our scheme is capable of simulating the streaming delivery method as well as the download delivery method. The details for each method are presented in the remaining of the Section.

B. Streaming Delivery Method

For the investigation of streaming delivery method, transmissions over both HS-DSCH and FACH channels are simulated. In the case of HS-DSCH, our simulation scheme calculates the required transmission power for the delivery of streaming data over MBMS. The power depends on the number of users and, therefore, an average of up to 20 users per cell is examined. It should be noted that the use of HS-DSCH for the MBMS data delivery towards more than 20 users per cell is meaningless since it causes a large waste of power in comparison with the use of FACH [6]. During the simulation of the streaming delivery over HS-DSCH channel and depending on the power level used by the base station, the BLER caused by the channel is set by the scheme to a certain level. By setting a required BLER target at the receiver, an appropriate amount of FEC redundant symbols are added by the sender in order for the receiver to retrieve the streaming data with the required BLER after the FEC decoding.

FACH transport channel is multiplexed to an S-CCPCH; therefore there are specific data rates that are achieved depending on the S-CCPCH slot format. In our simulation S-CCPCH with slot format 10 is used in order to achieve a 64 Kbps data rate [1]. During our experiments, we choose to simulate a media data stream of 64 Kbps bit rate and, since FEC encoding adds redundant symbols to the source data, it is not possible to use FEC encoding without transmitting through a higher level of S-CCPCH data rate. This means that 128 Kbps, corresponding to slot format 12, would be necessary to deliver both the 64 Kbps media streams and the FEC redundant information. Obviously, the use of slot format 12 for the transmission of a 64 Kbps media stream causes a large waste of power resources. Thus, we have chosen not to use FEC encoding for the streaming data delivery over FACH. The BLER target for the FACH data delivery is set to 1% and therefore the required transmission power for the various cell coverage levels is given by TABLE I.

For the assessment of streaming delivery method the delivery of a media data stream of 64 Kbps bit rate with BLER target set to 1% over both HS-DSCH and FACH channels is simulated. It should be clarified that the BLER target is the BLER that results after the FEC decoding at the receiver and is determined by the probability $p_f(m,k)$. This means that the actual BLER at the radio channel might be larger than 1%.

In the case of transmission over HS-DSCH, four scenarios are examined:

- Streaming delivery over HS-DSCH channel without FEC and channel BLER set to 1%.
- Streaming delivery over HS-DSCH channel with FEC and channel BLER set to 5%.
- Streaming delivery over HS-DSCH channel with FEC and channel BLER set to 10%.
- Streaming delivery over HS-DSCH channel with FEC and channel BLER set to 20%.

In the three latter cases the BLER target after the FEC decoding at the receiver is set to the required one (i.e. 1%).

P-t-p transmissions over HS-DSCH are more efficient for a limited number of users. In case the number of receivers exceeds a certain threshold, the application of p-t-m transmission is recommended [6]. Therefore in our analysis we use the power levels of p-t-m transmission over FACH as a reference for an efficient channel selection. In more detail, the delivery of the same media stream over FACH without application level FEC has been also simulated. The BLER applied at this type of transmission is also set to the target 1%.

The simulation results for the streaming delivery method are illustrated in Figure 1. Figure 1 shows the required transmission power to deliver the 64 Kbps media stream over the examined channels as a function of the number of receivers. The three levels of FACH transmission power illustrated in Figure 1 correspond to the required power for the percentages of cell coverage (70%, 90%, and 100%) that are indicatively selected and are presented in TABLE I.

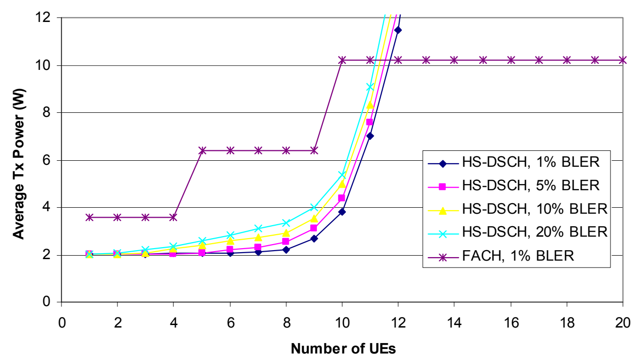


Figure 1 – Average transmission power for the delivery of a 64 Kbps media stream. BLER target is set to 1%.

What can be easily observed in Figure 1 is that for relatively large number of receivers, the addition of FEC encoding increases the required transmission power. For instance, the delivery of the media stream to eight MBMS users over an HS-DSCH channel with 20% BLER requires 47% more power than the delivery over an HS-DSCH channel with 1% BLER. Therefore the increment in power consumption that is caused by the redundant symbols of FEC encoding with Raptor codes is much higher in comparison with the increment needed in order to achieve a lower BLER. On the other hand, in case of relatively small number of receivers the required power for the transmission with FEC encoding closely matches the required power when no FEC is supported.

Last but not least, our experimental results show that when the number of receivers exceeds a certain threshold, the power consumption of HS-DSCH increases rapidly, thus the application of p-t-m transmission becomes more efficient. For the examined network configuration this threshold is 10 to 11 multicast receivers depending on the BLER which is applied.

C. *Download Delivery Method*

For the purpose of the investigation of download delivery method, the transmission of data files over both HS-DSCH and FACH channels is simulated. Contrary to the streaming delivery, application level FEC with Raptor codes is applied over both types of transport channels. Our scheme for the download delivery method follows the recommendation as specified by 3GPP in [2]. In more detail, both techniques of FEC with Raptor codes and ARQ are applied to provide a reliable data download delivery and therefore our scheme has a hybrid functionality regarding error control. Moreover, 3GPP recommends that the retransmission may be performed over a selective unicast context, since in some cases the setup of a new multicast bearer for packet retransmission is rather costly.

The scheme that we have designed and implemented combines both of the fundamental repair processes and therefore combines the following contexts:

- MBMS multicast bearers and application level FEC with Raptor codes.
- Unicast bearers for selective retransmission of lost packets.

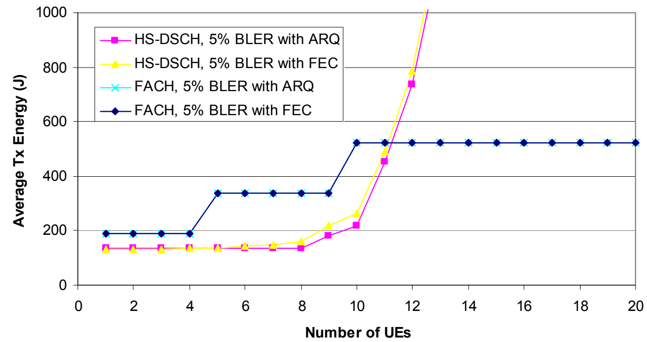
It is worth to explain that when a certain BLER is applied over the MBMS bearer, the number of the received symbols *m* may become less than the *n* symbols that were initially transmitted. As a result of the packet losses, the failure probability $p_f(m,k)$ increases. If the recovery of the *k* source symbols through decoding procedure fails in a UE, then ARQ is invoked by the UE for the retransmission of the lost packets from the BM-SC over a unicast context.

The basic scenario that we simulate for the evaluation of FEC power efficiency during download delivery is that a file of a certain size with static contents is transmitted in multicast mode to a group of users which are randomly placed in each serving cell. We have chosen to simulate the distribution of a 512 KB file which might represent a short multimedia clip, a still image or a reasonably sized ring tone. For the finally presented results, bearers supporting 64 Kbps have been chosen. Simulations are run for various numbers of MBMS receivers per cell whereby their starting position is randomly and uniformly distributed over each cell area.

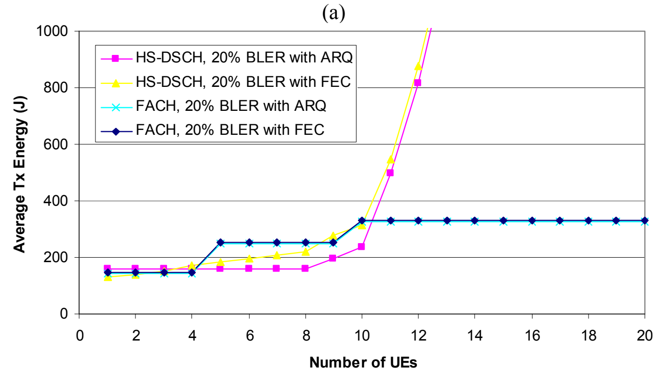
Our scheme for download delivery method uses both HS-DSCH and FACH channels for the transmission of data files. Contrary to the streaming delivery simulation, application level FEC with Raptor codes is applied over both types of transport channels. In the assessment of the various channel configurations for the download delivery method, basically three aspects are of major interest, the required transmission power, the consumed transmission energy and the necessary download time.

The required transmission power is almost the same as that of streaming delivery case which is depicted in Figure 1. Some minor differences exist and are caused by the sizes of the MBMS User Services packet headers (RTP vs. FLUTE). In fact, the streaming protocol headers are simpler and therefore a slightly less transmission power is needed in comparison with the protocol headers used for the download service. The results for average total transmission power during download data delivery are not depicted due to space limitations and the reader is referred to Figure 1.

The other aspect that we examine during our simulation experiments is the consumed transmission energy. The minimization of energy consumption for the transmission of a given data portion is an important goal for mobile operators and therefore the required transmission energy is a critical metric. During our assessment different BLER are applied over the channels and the energy requirements of each channel configuration is examined for various users' distributions. The BLER that are applied are 5% and 20%. The required energy is estimated in terms of Joules (J) where 1 J = 1 W • 1 sec. The results of our simulations are presented in the following figures.



(a)



(b)

Figure 2 – Average total transmission energy for the delivery of the distributed file. BLER is set to (a) 5%, and 20%.

From the simulation results it is immediately observed that, from transmission energy point of view, the switching point where the p-t-m transmission over FACH turns to be more efficient is a number of 10 to 11 mobile users. In more detail, all the simulation results show that the download delivery over HS-DSCH is more expensive for download delivery of a file when the UEs are more than 10. The transmission over FACH even with 100% cell coverage is more efficient from energy perspective as the receivers become more than 10.

Another interesting observation is that the use of application level FEC adds a minor overhead at the total transmission energy over the p-t-m channel. Although this overhead is not clear from Figure 2 where the two curves almost coincide, the simulation logs show that this overhead varies from 1.1% to 1.5%. Nevertheless, during p-t-m transmission the 64 Kbps bit rate level has to be kept and, since FEC encoding adds redundant symbols to the source data, a longer transmission time is necessary for the delivery of the distributed file.

On the other hand, when the transmission is made over p-t-p channel (HS-DSCH) there is the flexibility to achieve a download time that corresponds to 64 Kbps bit rate. Therefore, the transmission of the total amount of the encoding symbols (encoding symbols are the source symbols plus the redundant ones added due to the FEC encoding) is performed at the higher bit rate. This causes an increment in the p-t-p total transmission energy from 10% to 25% (Figure 2). From the above results it is obvious that for non time-constrained transmissions it is considerably advantageous to keep low the transmission energy.

In terms of users perception, file download is in some sense only binary, namely it is evaluated if the file is correctly received or not. On the other hand, there is an aspect that can be considered as strongly connected with user perception: that is the experienced download time. In other words, we evaluate how long it takes to receive the file after the joining has happened. Figure 3 presents the average experienced download time for each channel configuration.

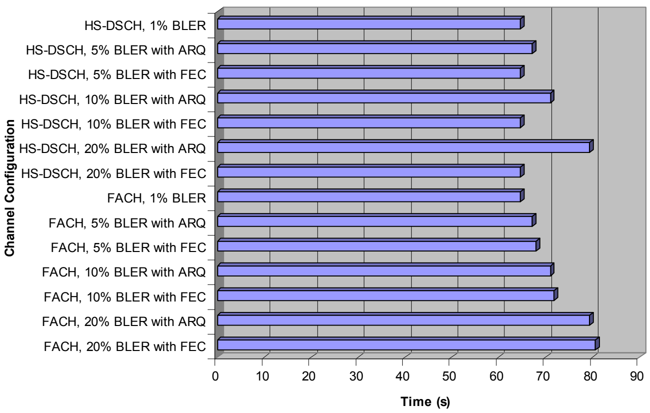


Figure 3 – Average total transmission time for the delivery of the distributed 512 KB file.

When comparing the average download times for the various channel configurations, we conclude that using a p-t-m channel can be more time consuming. This is reasonable since a fixed bit rate level of 64 Kbps has to be followed. This means that any redundant symbols added by the FEC encoding or any additional packet retransmissions cause an extension of the user perceived download time.

On the other hand the p-t-p channel offers the flexibility to regulate the transmission bit rate to any desired level. Therefore, by increasing the transmission power any additional redundant symbols or any retransmitted packets are transferred without affecting the bit rate of 64 Kbps.

IV. CONCLUSIONS

In general, it is concluded that the use of application layer FEC causes an increment at the power consumption in comparison with the traditional ARQ. In other words increasing the power in order to succeed a better BLER is cheaper from power perspective than increasing the power to send the redundant symbols added by FEC encoder. This is applicable for time constrained transmission, i.e. for transmissions that should be completed at a given bit rate (for streaming delivery) or in a given download time (for download delivery). On the other hand, it is concluded that the use of application layer FEC causes a relatively small increment at the power consumption also in comparison with the traditional ARQ. Another general conclusion is that the use of HS-DSCH offers a large flexibility in the selection of the actual bit rate and the amount of redundant symbols used. Instead, FACH offers only specific bit rate levels. The use of Raptor codes FEC encoding does not therefore offer downlink power savings. Instead the benefits of FEC are strongly connected with the uplink direction, mainly with its operability even with limited or no uplink resources and the avoidance of feedback implosion that it offers.

In the case of streaming delivery our experimental results show that when the number of receivers exceeds the threshold of 10 to 11 users, the power consumption of HS-DSCH increases rapidly, thus the application of p-t-m transmission over FACH becomes more efficient. The evaluation of download delivery shows clearly that both from energy and power perspective the switching point for download delivery method is the same threshold of 10 to 11 users. The last but not least aspect that we have examined is the total transmission time. Its importance stems from its association with user perception since it coincides with the user experienced download time. The evaluation of the total transmission time shows that the use of p-t-m channel can be more time consuming since a fixed bit rate level of 64 Kbps has to be followed. This means that any redundant symbols added by the FEC encoding or any additional packet retransmissions cause an extension of the user perceived download time. This does not happen in the case of the p-t-p channel due to the flexibility that it offers to regulate the transmission bit rate to any desired level.

REFERENCES

[1] 3GPP, TR 25.803 V6.0.0, Technical Specification Group Radio Access Network; S-CCPCH performance for MBMS; (Release 6), Sep. 2005.

[2] 3GPP, TS 23.246 V9.0.0. Technical Specification Group Services and System Aspects; MBMS; Architecture and functional description (Release 9), Jun. 2008.

[3] 3GPP, TS 25.308 V9.0.0. Technical Specification Group Radio Access Network; High Speed Downlink Packet Access (HSDPA); Overall description; Stage 2 (Release 9), Jun. 2009.

[4] 3GPP, TS 25.346 V8.3.0. Technical Specification Group RAN; Introduction of the MBMS in the RAN; Stage 2 (Release 8), Mar. 2009.

[5] A. Alexiou, C. Bouras, and A. Papazois, "Adopting Forward Error Correction for Multicasting over Cellular Networks", Proc. European Wireless (EW2010), Apr. 2010, in press.

[6] A. Alexiou, C. Bouras, V. Kokkinos, and E. Rekkas, "An improved mechanism for multiple MBMS sessions assignment in B3G cellular networks", Wireless Netw, 2009 (Published online).

[7] E. Dahlman, S. Parkvall, J. Sköld, and P. Beming, 3G evolution: HSPA and LTE for mobile broadband (2nd edition). Elsevier, 2008.

[8] H. Holma and A. Toskala, WCDMA for UMTS: HSPA evolution and LTE (4th edition). John Wiley & Sons, 2007.

[9] M. Luby, T. Gasiba, T. Stockhammer and M. Watson, "Reliable Multimedia Download Delivery in Cellular Broadcast Networks", IEEE Trans. Broadcasting, vol. 53, no. 1, Mar. 2007, pp. 235-246.